Differential expression of dimethylglycine dehydrogenase in cancers of the breast.

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Breast cancer affects women at relatively high frequency¹. We mined published microarray datasets^{2,3} to determine in an unbiased fashion and at the systems level genes most differentially expressed in the primary tumors of patients with breast cancer. We report here significant differential expression of the gene encoding dimethylglycine dehydrogenase, DMGDH, when comparing primary tumors of the breast to the tissue of origin, the normal breast. DMGDH mRNA was present at significantly lower quantities in tumors of the breast as compared to normal breast tissue. Analysis of human survival data revealed that expression of DMGDH in primary tumors of the breast was correlated with overall survival in patients with basal-like and normal-like subtype cancer, demonstrating a relationship between primary tumor expression of a differentially expressed gene and patient survival outcomes influenced by PAM50 molecular subtype. DMGDH may be of relevance to initiation, maintenance or progression of cancers of the female breast.

Keywords: breast cancer, DMGDH, dimethylglycine dehydrogenase, systems biology of breast cancer, targeted therapeutics in breast cancer.

Invasive breast cancer is diagnosed in over a quarter of a million women in the United States each year¹ and in 2018, breast cancer was the leading cause of cancer death in women worldwide⁴. While patients with localized breast cancer are provided a 99% 5-year survival rate, patients with regional breast cancer, cancer that has spread to lymph nodes or nearby structures, are provided an 86% 5-year survival rate^{5,6}. Patients with metastasis to distant sites, like the brain, are provided a 27% 5-year survival rate^{5,6}. Understanding how primary tumors are most transcriptionally different from the tissue from which they originate, the breast, can facilitate development of novel diagnostic and therapeutics to promote early detection and enhanced treatment, and contribute to efforts to prevent progression to metastatic stages. We mined published microarray data^{2,3} to understand at the transcriptome level and in an unbiased fashion genes most differentially expressed in primary tumors of the breast as compared to normal breast tissue. dimethylglycine dehydrogenase emerged as among the most differentially expressed genes in cancer of the female breast.

Methods

We utilized datasets GSE42568² and GSE109169³ for this global differential gene expression analysis of female breast cancer. GSE42568 was generated using Affymetrix Human Genome U133 Plus 2.0 array technology with $n=17$ normal breast tissue biopsies and $n=104$ primary breast tumor biopsies from patients with breast cancer; analysis was performed using platform GPL570; the majority of patients whose tumors were analyzed were age 50 or older. GSE109169 was generated using Affymetrix Human Exon 1.0 ST Array technology with $n=25$ normal breast tissue and $n=25$ tumors of the breast; analysis was performed using platform GPL5175. The tissues whose expression was profiled in this dataset are paired tissues (25 tumors matching 25 breast tissues from 25 patients). The Benjamini and Hochberg method of p -value adjustment was used for ranking of differential expression but raw p -values were used to assess statistical significance of global differential expression. Log-transformation of data was auto-detected, and the NCBI generated category of platform annotation was used. A statistical test was performed to evaluate whether DMGDH expression was significantly different between primary breast tumors and normal breast tissue using a two-tailed t-test. For Kaplan-Meier survival analysis, we used the Kaplan-Meier plotter online tool⁷ for correlation of DMGDH mRNA expression levels with overall survival (OS) in $n=296$ patients with basal-like subtype cancer, $n=222$ patients with luminal A subtype cancer, $n=200$ patients with luminal B subtype cancer, $n=198$ patients with HER2+ cancer, and $n=27$ patients with normal-like subtype cancer.

Results

We performed discovery of genes associated with breast cancer in females by mining two independently published microarray datasets^{2,3}.

DMGDH is differentially expressed in primary tumors of the breast.

Studying the global gene expression profiles of 104 breast cancers from patients aged 31 to 89 revealed that the gene encoding dimethylglycine dehydrogenase, DMGDH, was among the genes most differentially expressed in tumors of the breast in human breast cancer (Chart 1). When sorting each of the genes expressed in tumors of the breast based on significance of difference as compared to normal breast tissue, DMGDH ranked 59 out of 54675 total transcripts, equating to 99.9% differential expression (Chart 1). Differential expression of DMGDH in female breast cancer was statistically significant (Chart 1; $p=6.34E-34$).

Analysis of a second microarray dataset³, here studying global gene expression patterns in the tumors of 25 patients with early-onset breast cancer, again revealed significant differential expression of

DMGDH in human breast cancer (Chart 2). When sorting each of the genes expressed in the tumors of patients with breast cancer based on significance of difference as compared to normal breast tissue, DMGDH ranked 1875 out of 19076 total transcripts, equating to 90.2% differential expression (Chart 2). Differential expression of DMGDH in the tumors of patients with breast cancer was statistically significant (Chart 2; $p=4.72E-07$). These data suggested that differential expression of DMGDH was not an artifact of a single microarray dataset, nor was it strictly associated with early-onset breast cancer, rather a general feature of cancers of the breast.

DMGDH is expressed at significantly lower levels in breast tumors as compared to the breast.

We obtained exact mRNA expression levels for DMGDH from the breast and from breast tumors to understand the magnitude and direction of DMGDH expression change. DMGDH was expressed at lower levels in tumors of the breast as compared to normal breast tissue (Figure 1). Decreased expression of DMGDH in primary breast tumors was statistically significant (Figure 1: $p<0.0001$). DMGDH was expressed at 5.04 ± 1.53 arbitrary units (AU) in normal breast tissue, while it was expressed at 2.38 ± 0.23 AU in tumors of the breast. We calculated a mean fold change of 0.47 in DMGDH mRNA levels when comparing primary tumors of the breast to normal breast tissues.

DMGDH expression correlates with survival outcomes in basal-like and normal-like subtype human breast cancer.

We performed Kaplan-Meier survival analysis to study relationships between tumor DMGDH mRNA expression levels and survival outcomes in patients with breast cancer. We observed a correlation between DMGDH expression and overall survival (OS) in patients with basal-like subtype breast cancer which trended towards statistical significance (Figure 2; log rank p -value: 0.076 for overall survival, hazard ratio: 0.65 (0.41-1.05) (Fig. 2)). DMGDH mRNA levels were a positive prognostic indicator in basal-like subtype breast cancer patients. Median OS was 47.67 months for basal-like patients with low tumor expression of DMGDH while median OS was 89.04 months for basal-like patients with high tumor expression of DMGDH (Chart 3).

We also observed a correlation between DMGDH expression and overall survival (OS) in patients with normal-like subtype breast cancer which trended towards statistical significance (Figure 2; log rank p -value: 0.072 for overall survival, hazard ratio: 3.35 (0.83-13.51) (Fig. 2)). DMGDH mRNA levels were a negative prognostic indicator in normal-like subtype breast cancer patients. Median OS was 78 months for normal-like patients with low tumor expression of DMGDH while median OS was 21 months for normal-like patients with high tumor expression of DMGDH (Chart 3).

DMGDH primary tumor expression was not correlated with overall survival in luminal A breast cancer (Figure 2; log rank p -value: 0.33 for OS, hazard ratio: 0.7 (0.34-1.44) (Fig. 2)), luminal B subtype breast cancer (Figure 2; log rank p -value: 0.67 for OS, hazard ratio: 1.13 (0.65-1.97) (Fig. 2)), or in HER2+ breast cancer (Figure 2; log rank p -value: 0.61 for OS, hazard ratio: 0.87 (0.51-1.49) (Fig. 2)).

Thus, through comparative transcriptome analysis of primary tumors of the breast and normal breast tissue, we found that differential expression and down-regulation of DMGDH was among the most significant transcriptional features in primary tumors from patients with breast cancer. DMGDH expression in primary tumors of the breast was correlated with overall survival in patients with basal-like and normal-like subtype disease, with mRNA levels of DMGDH a positive prognostic indicator for basal-like but a negative prognostic indicator for normal-like breast cancer patients.

Discussion

Invasive breast cancer is a medical problem with a 27% 5-year survival rate for women whose

1 disease has spread to distant sites^{5,6}. To facilitate understanding of the basic transcriptional differences
2 between primary tumors of the breast and the tissues from which these tumors originate, normal breast
3 tissues, we performed comparative transcriptome analysis using two independently published microarray
4 datasets^{2,3}, providing evidence here that differential expression of dimethylglycine dehydrogenase,
5 encoded by DMGDH, is a defining transcriptional feature of human breast cancer: in patients diagnosed
6 after age 50, and in early onset-breast cancer. DMGDH was expressed at significantly lower levels in
7 primary tumors from patients with breast cancer as compared to normal breast tissue. Importantly, in
8 patients with basal-like and normal-like subtype breast cancers, expression of DMGDH was correlated
9 with overall survival. dimethylglycine dehydrogenase and the molecular processes to which it pertains to
10 may be relevant to the initiation or progression of human breast cancer.
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Rank: 59
Probe ID: 231790_at
p-value: 6.34E-34
t: 1.71E+01
B: 66.6059195
Gene: DMGDH
Gene name: dimethylglycine dehydrogenase

Chart 1: DMGDH is differentially expressed in the primary tumors of patients with breast cancer.

Rank of differential expression, probe ID, p-value of global differential expression, t, a moderated t-statistic, B, the log-odds of differential expression between the groups compared, gene and gene name are listed in this chart.

Rank: 1875
Probe ID: 2864118
p-value: 4.72E-07
t: 5.77
B: 5.928112
Gene: DMGDH
Gene name: dimethylglycine dehydrogenase

Chart 2: DMGDH is differentially expressed in the primary tumors of patients with early-onset human breast cancer.

Rank of differential expression, probe ID, p-value of global differential expression, t, a moderated t-statistic, B, the log-odds of differential expression between the groups compared, gene and gene name are listed in this chart.

Figure 1: DMGDH is expressed at significantly lower levels in primary breast tumors as compared to normal breast tissue.

The mRNA expression level of DMGDH in normal breast tissue (left) and in primary tumors of the breast (right) is graphically depicted with the result of a statistical test evaluating significance of difference in DMGDH expression between normal breast tissue and primary tumors of the breast, a *p*-value, listed above.

Figure 2: DMGDH expression correlates with overall survival in patients with basal-like and normal-like subtype breast cancer, but not in patients with luminal A, luminal B, or HER2+ subtype cancer.

Depicted in this Kaplan-Meier plot is the probability of overall survival (OS) for $n=296$ patients with basal-like breast cancer (upper left), $n=198$ patients with HER2+ breast cancer (upper right), $n=222$ patients with luminal A breast cancer (middle left), $n=200$ patients with luminal B breast cancer (middle right), and $n=27$ patients with normal-like breast cancer (below) stratified into two groups, based on low or high expression of DMGDH in patient primary tumors. The log rank p-value denoting statistical significance of difference in overall survival when comparing the two groups, as well as hazard ratio for this comparison is listed above. Listed below is the number of patients at risk (number of patients alive) per interval, after stratification based on DMGDH expression; in the first interval, number at risk is number of patients alive; in each subsequent interval, number at risk is the number at risk less those who have expired or are censored.

Basal-like patients

Low DMGDH expression: 47.67 months

High DMGDH expression: 89.04 months

Normal-like patients

Low DMGDH expression: 78 months

High DMGDH expression: 21 months

Chart 3: In basal-like subtype breast cancer, median overall survival is superior in patients with high primary tumor expression of DMGDH, but in normal-like subtype breast cancer, median overall survival is superior in patients with low primary tumor expression of DMGDH.

The overall survival of $n=296$ basal-like subtype breast cancer patients and $n=27$ normal-like subtype breast cancer patients based on stratification into low or high tumor expression of DMGDH is listed in this chart.